Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 520-521

P-6-13

Influence of Crystal Polarity on N- and Ga-polarity GaN Metal-Semiconductor-Metal Ultraviolet Sensors

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1. Introduction

A critical property of wurtzite group III-nitride is its large spontaneous and piezoelectric polarization [1]. This will strongly influence the preference of electronic and optoelectronic devices [2]. One of the consequences of large polarization is the existence of large densities of different fixed charges at the heterostructure interfaces. In addition, the direction of the electric field induced by these fixed charges is strongly dependent on the growth direction, i.e., Ga-polar or N-polar.

As for molecular beam epitaxy (MBE) system, the polarities of GaN layers are more sensitive to the type of buffer layer and the growth conditions [3,4]. Nevertheless, the growth of Ga-polarity GaN is usually achieved by metalorganic chemical vapor deposition (MOCVD), whereas N-polarity GaN is difficult to be produced by MOCVD thus far. Metal-semiconductor-metal (MSM) ultraviolet (UV) sensors have attracted much attention because of their simple structure and having high responsivity. MSM structures are also useful in optoelectronic integrated-circuits (OEICs) since they are easy to integrate, highly potential for high-speed application, and compatible with field effect transistor (FET) process technologies [5].

Experimental report for MSM sensors on N-polarity GaN is rare to be seen so far, mainly because N-polarity GaN layers is difficult to be produced by MOCVD. In this study, we investigate the polarities of MOCVD grown GaN films by introducing Al intermediate layer process during growth, and a comparison between MSM UV sensors on N-polarity and Ga-polarity GaN will be discussion.

2. Experiments

The GaN films used in this study are grown on c-face (0001) sapphire substrates by MOCVD. Ttrimethylgallium (TMGa), ammonia (NH_3) and trimethylaluminum (TMAl) are used as the sources of gallium, nitrogen and aluminum, respectively. The carrier gas is hydrogen (H_2), and the growth pressure is 100 Torr. Prior to the growth, the substrate is initially heated to 1100°C in H_2 ambient for cleaning the surface of substrate and then lowered to 550°C in order to grow a 30 nm-thick low-temperature GaN buffer layer. Temperature is subsequently raised to 1000°C to grow a 2-μm-thick undoped GaN layer. TMAl is then introduced to reverse the Ga-polarity to N-polarity of GaN. Finally, 1 μm-thick undoped GaN epilayer is deposited on the top of the Al intermediate layer (i.e. sample A). For comparison, a 2 μm-thick undoped GaN film without Al intermediate layer is also prepared under the same growth conditions (i.e., sample B). Second ion mass spectrometry (SIMS) depth profile analysis is executed to study the distributions of Al, Ga and N in these two as-grown samples. These two samples are then immersed into 10N-KOH solution for 5 minutes to identify the lattice polarity [6,7].

Next, the MSM UV sensors are fabricated by using these two samples. After mesa etching for 0.5 μm, the Ni(5nm)/Au(5nm) are deposited by electron-beam evaporator as the Schottky contact, and subsequently thermal annealing at 550 °C for 3 minutes for alloying.

3. Results and Discussion

Figure 1 shows the measured SIMS profiles of Ga, N and Al for these two as-grown samples. A comparison with sample B, sample A shows the presence of Al in the region of 1 μm. Such a result agrees well with our initial design.

According to property of the Ga-polarity GaN, we know that it has more chemical stability than N-polarity GaN [6]. After chemical etching, it is found that the crystalline structure of sample A becomes poor rapidly by XRD, AFM and SEM measurements (not shown here) [7], but the sample B remains the original one. The observed results suggest that the polarity of GaN film can successfully transform the Ga- to N-polarity by introducing an Al intermediate layer during growth in MOCVD. In addition, the measured surface morphologies of as-grown GaN films with different polarity show that the N-polarity GaN is much rougher than Ga-polarity GaN.

Room-temperature current-voltage (*I-V*) characteristics of these two polarity GaN MSM UV sensors are then measured by a HP4155B semiconductor parameter analyzer in the dark and under illumination as shown in Fig. 2. During photocurrent measurements, light generated from a xenon (Xe) arc lamp through a calibrated monochromator is used as the optical source. The monochromatic light is then illuminated onto the front side of the fabricated GaN MSM UV sensors. Under reverse bias voltage, the dark current is near a constant of around 3.9×10^{-11} A for sample A sensor. In contrast, the dark current of sample B sensor is at about one order of magnitude smaller than sample A senor. This phenomenon could be attributed to the Schottky barrier height of sample A senor is lower than sample B senor [8,9]. On the other hand, the photocurrent of sample A sensor is greater than that of sample B sensor. The larger photocurrent generated form N-polarity GaN MSM UV sensor can be attributed to that the more incident photons

absorbed easily and reduction of total reflection for incident light by naturally textured N-polarity GaN surface.

Spectral responsivity of these GaN MSM UV sensors is also measured using a Xe arc lamp with a calibrated monochromator as the light source. Figure 3 shows the spectral response of sample A and sample B sensors, respectively. It is found that cutoff wavelength is around 370 nm for both samples. The UV-to-visible rejection ratio is defined as the ratio of responsivity measured at 350 nm to that measured at 450 nm. With a 5V bias voltage, the UV-to-visible rejection ratios are around 20 and 14 for sample A and sample B sensors, respectively. Such a dramatic difference could be attributed to the larger photocurrent measured in sample A sensor. In addition, for sample B sensor one can see that the sub-bandgap response is larger than sample A sensor. This might be due to the higher surface-state density in sample B sensor [10].

4. Conclusions

Nitride-based MSM UV sensors fabricated with various polarity GaN layer have been investigated. It is found that dark current of N-polarity GaN sensor is higher than that of Ga-polarity one. This is attributed to Schottky barrier height of N-polarity GaN sensor being lower than Ga-polarity one. Besides, the results of photocurrent and responsivity for N-polarity GaN sensor show that it is superior to Ga-polarity GaN one. The observed results indicate that the randomly textured surface of N-polarity GaN can enhance the light absorption and reduce the reflecion of incident light for the applications of MSM UV sensors.

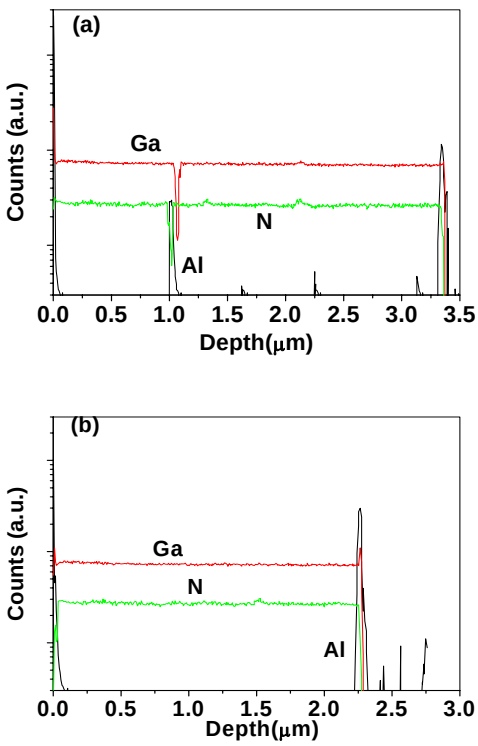

Fig. 1. Al, Ga and N depth profiles measured by SIMS analysis for as-grown GaN layers (a) sample A and (b) sample B.

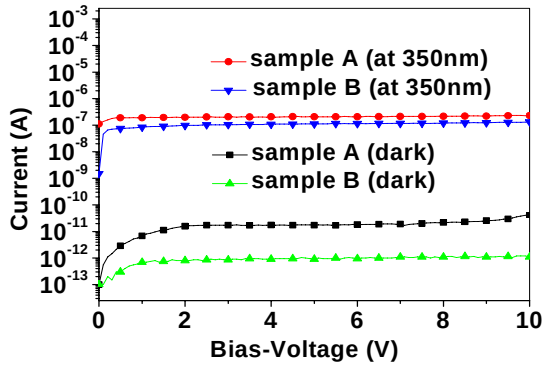

Fig. 2. Room temperature *I–V* characteristics of samples A and B sensors measured in the dark and under illumination.

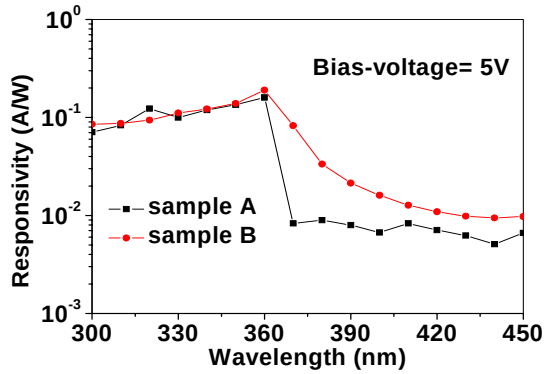

Fig. 3. Spectral responsivity of the fabricated MSM UV sensors under 5 V bias voltage.

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